whose center was at a distance of 750 miles, some 20 hours before we received the Government notice of its presence, and two days before the center reached us.

On Thursday, August 22, of the present year we received our first notice from the United States Weather Bureau of a disturbance located to the southeast of Barbados. On August 23 we were warned by the local bureau to take all possible precautions as the disturbance would probably reach us on Saturday morning. Friday night was clear, and we hastened to the telescope, but to our surprise not a trace of any hurricane lines could be found. The star image was "moulding," however—that is to say, it looked as if it were being moulded by the fingers first in one place and then in another. This indicates local atmospheric disturbances. The seeing was poor, 6, later dropping to 5 on a scale of 12, but was not extremely bad, such as is the case in the vicinity of a hurricane. We therefore retired considerably relieved, in spite of the warnings. The next day the sky was heavily overcast, but with no rain and only moderate winds, and we were informed by the United States Weather Bureau that there was no definite information as to the location of the disturbance. As it turned out the hurricane either had not developed or had taken a more northerly course.

From this we conclude that telescopic observations of the kind described are of value in the local forecasting of tropical storms, not only to foretell their approach and the direction of their motion, but also sometimes to inform us that other indications are not to be trusted.

OCEAN TEMPERATURES IN LONG-RANGE FORECASTING.

By CHARLES F. BROOKS.

[Paper presented at the Baltimore meeting of the Association of American Geographers, Dec. 28, 1918.]

"Besides trying to predict the extremely variable state of the fickle atmosphere one should give more attention to the conservative element of meteorology, viz, the surface sheet of the ocean where changes may be observed months before their effect on our weather becomes manifest. [For example] a sensible departure from the average value of the vast amount of stored heat carried through the [Florida] Straits might have profound effects on the weather of the following months on the European and North American Continents."

These two sentences by Dr. Hans Petterson[1] led me to compare monthly departures of air temperature at stations in the eastern United States with those in the Gulf Stream. Encouraged by the results, I extended the investigation backward into the make-up of the Gulf Stream and Antilles Current, forward into the movement of the Gulf Stream Drift, and the effects of the Labrador Current, and upward into the influence of water temperatures on the overlying air. A report on the preliminary results just a year ago led to the active cooperation of the Weather Bureau in mapping more data, and later the Signal Corps offered additional help.

Let me outline the general basis which seems to make worth while the contemplated extensive investigation of ocean temperatures in long-range forecasting. If it is possible (1) to forecast the distribution of surface water temperature a few weeks in advance, it may prove possible (2) to forecast the general paths which will be followed by cyclones and anticyclones; and then (3), from the winds which will result, to make long-range forecasts of the general weather to be expected in any period. Let us consider each of these points more in detail.

1. *How do water surface temperature departures originate and move?*

Insolation and radiation are the most important factors in the general heating and cooling of the ocean surface. The temperature of the air is of little consequence in the heating, and still less in the cooling, of the ocean surface, for the specific heat of water per unit volume is about 3,300 times that of air under ordinary conditions.

Departures of the temperatures of the sea surface from the normal are almost wholly the result of variations in wind direction and velocity. Helland-Hansen and Nansen have shown in their recent book[2] that in middle latitudes of the Atlantic the wind direction is largely responsible for the occurrence of plus and minus temperature departures. Following a winter month with the prevailing wind north of the normal over any region, the water temperatures are almost invariably below normal, while a month with prevailing winds south of normal is followed in the next by water temperatures above normal. The air temperature, of course, shows similar, though greater and more immediate, departures. The coldness or warmness of the water is probably dependent more on transportation of water from colder or warmer latitudes than on the cooling or warming by the wind which is driving it. At any rate the evaluation of each factor is of little consequence for both act to produce the same result.

The effect of changes in wind velocity is most noticeable in the Tropics, where changes in direction are of little or no effect. When the trade winds are unusually strong for a period, the warm layer of surface water is driven forward and concentrated in the Equatorial Current, where it forms a plus departure in temperature. The place of this warm surface sheet is taken by cooler subsurface water, making a minus departure. Under the influence of the wind the area of plus departure followed by that of minus moves slowly westward. Using Hepworth's data,[3] I found that most months of unusually strong northeast trade winds in the eastern Atlantic are followed in 4 to 6 months by plus departures in the temperature of the surface water passing through the Straits of Florida, and in 8 to 11 months by minus departures. The southeast trade in the eastern Atlantic, acting through the South Equatorial Current, part of which feeds the Gulf Stream, produces a similar plus and then minus departure in the Straits of Florida, 6 to 9 and 10 to 14 months, respectively, after the month of unusually strong southeast trade.

What happens to these waters of varying temperature as they debouch into the Atlantic? The strength of the Gulf Stream carries them forward to the region south of Nantucket within a month; but their identities are not lost for several months more in the case of water markedly warmer or colder than usual. In fact, in spite of the obliterating effects of shifting winds of varying strengths, many of the water temperature departures observed in the Gulf Stream, Antilles Current, or Labrador Current are discernible many months later on the coast of Europe, especially when the water has made most of the transit in the quieter months of the year. From the Straits of

[1] Meteorological Aspects of Oceanography, M. W. R., June, 1916, 44: 338-341, 2 figs.

[2] Temperatur-Schwankungen des Nordatlantischen Ozeans und in der Atmosphäre Christiania, 1917. See author's abstract, M. W. R., April, 1918, 46: 177-178.

[3] M. C. W. Hepworth, The Trade Winds of the Atlantic Ocean. Metl. Office, London, No. 203, 1910.

Florida to the edge of the European continental shelf at about latitude 50 degrees, the temperature departures take 8 to 10 months. The effects of changes in the Labrador Current on the Grand Banks take equally long. But the departures in the Antilles Current east of the Bahamas take but 5 to 7 months to cross the Atlantic.

Think of the travels of an important plus temperature departure, for instance, between latitudes 5° and 45° in the North Atlantic. Originating, perhaps, in the eastern Atlantic during a month of strong trades (the strength of which may still farther back depend on the water temperature distribution) and proceeding across the Atlantic, many of these departures in the course of 4 to 6 months pass through the Straits of Florida; and in 8 to 10 months more they may be felt off the west coast of Europe. Thence some of the important departures may complete the circuit and appear in the Straits of Florida 15 months still later. In spite of the great complexities introduced by changing winds, it is evident that there are possibilities of forecasting the distribution of ocean surface temperatures.

2. *How do these ocean temperatures control atmospheric pressure and winds?*

It is a matter of common knowledge that in autumn and winter in middle and high latitudes bodies of water are marked by low pressure areas because of their warmth, and in spring and summer by high pressure areas in the regions where the water is appreciably colder than the land. Many investigators have shown that this is true for particular months, and that peculiar water temperature distributions are marked by corresponding pressure features. As weather forecasters well know, the individual cyclones tend to follow paths across the warmer regions and to be intensified where there are sharp contrasts in temperature; and the anticyclones tend similarly to follow paths across the colder regions and to maintain the highest pressures over the coldest parts.

J. Petersen has described in detail how the Iceland LOW moves back and forth between southern Greenland and the Norwegian Sea in response to the changing distribution of water temperatures induced by its own winds.[4] When the Iceland LOW is west, the strong southwest winds in the eastern Atlantic bring warm air and drive warm water far northeastward; while northerly winds along the Greenland coast bring cold water southward. The rise of temperature in the east and the fall in the west favor a fall of pressure in the east and a rise in the west. Consequently, the center of lowest pressure moves eastward. But when the Iceland LOW is centered in the east, the northwest winds west of the British Isles drive cold water toward the coast of Europe; while farther north, warm water is being driven westward. The resulting cooling in the east and warming in the west favor a return of the center of the Iceland LOW to its first position; and the cycle begins anew.

The general circulation of the atmosphere favors high pressures in latitudes 25° to 40° and low pressures between latitudes 50° and 65°. The particular locations of the permanent and semipermanent centers of high pressure are likely to be the coldest spots in the low-latitude belt; while the centers of general low pressure will probably be in the warmest spots of the high-latitude belt. The intensities of these centers of action seem to be functions both of the strength of the general circulation and of the temperature contrasts in approximately the same latitudes.

3. *What weather occurs with winds which accompany any pressure type?*

A body of unusually warm water coming through the Straits of Florida, as in January, 1916, on spreading over the western Atlantic south and east of New England makes a very favorable region for cyclones. In consequence, we experience such unusual cold and snowy north and northeast winds as made the snowy winter of 1915–16 famous in the Middle and North Atlantic States.[5] In February, March, and April, of 1916, many cyclones approaching the Atlantic coast passed eastward, out to sea; became intense over the warm water, and then weakened over the cooler water beyond.[6] Thus, we have the paradox that an unusually warm Gulf Stream favors cold weather in the eastern United States, while a "cool" Gulf Stream favors warm weather.[7]

For the different pressure types the weather is well known, both in Europe and in this country; so, if the probable position and strength of the center of action can be forecast, the details will follow easily.

It is evident that general answers of a favorable kind, even though not firmly established, are already at hand for the three questions, and that much work has already been done. It remains to coordinate these results and to add considerably to the data already mapped. While we might be able to compute the subsequent pressure distribution from the present surface temperatures and winds, the problem is too complicated to be solved quickly in this way. We need to attack this problem in the same way that the daily forecasting difficulties were met; make a thousand maps, classify them according to types, and forecast empirically if the dynamic basis is not clear. While this is simple to say, the use of ocean temperatures in long-range forecasting will be a tremendously complicated proceeding. It seems probable that certain types of pressure distribution, as averaged for 10–30 day periods, can be associated with certain types of surface water temperature distribution. In making a forecast of the pressure distribution for month after next, for instance, it might be necessary to go through the following procedure: (1) Forecast how the water temperatures will change during the next 10 days under the action of the present winds; (2) forecast a slight rearrangement of the tracks of cyclones and anticyclones in accordance with this changed water surface temperature distribution; (3) apply the winds of this forecast pressure distribution to the movement of the water for the next 10 days; (4) go through the round a few times more; (5) as some kind of a check compare the results with the sequences on previous occasions following similar original pressure and water-temperature associations. Longer-range, more general forecasts might be made by watching closely the Gulf Stream in the Straits of Florida and the Japan Current off Formosa.

POSSIBLE APPLICATIONS TO THE NORTH PACIFIC REGION.

[Conclusion of a paper on "Possibilities of Long-Range Seasonal Weather Forecasts Based on Ocean Temperatures: With Especial Reference to an Investigation of the North Pacific," read at the conference on this subject during the semicentennial celebration of the founding of the University of California, Mar. 18–21, 1918.]

The first steps for an investigation of the North Pacific Ocean, in particular, would be to procure plenty of current atmospheric pressure and temperature data. The area is so vast that if we are to have a satisfactory

[4] "Unperiodische Temperaturschwankungen im Golf Strom und deren Beziehung ozu der Luftdruckverteilung." Am. d. Hydrog u. Mar. Met. 1910, 38:397–417, 2 pls.

[5] Cf. New England Snowfall, M. W. R., June, 1917, 46: 271–285, and Geogr. Rev., Mar., 1917, 3: 222–240.

[6] See the discussion of the marine data for November, 1917, on chart IX and p. 538 of this issue of the Review for a somewhat similar occurrence of a southwestward displacement of the Iceland LOW over an area of unusually high water temperatures.

[7] Cf. The "Old-Fashioned" Winter of 1917–18, Geogr. Rev., May, 1918, 5: 405–414.

picture of the weather and water conditions of the Pacific Ocean, all ships and all lighthouses operating in this region should be equipped to take water temperature and atmospheric pressure observations. These observations should be made available within a month of the time they are taken, if possible at some international establishment where they can be used immediately for the construction of maps. At this bureau, there could be a corps constantly engaged in mapping the data, getting averages for 10-day and 30-day maps, and making the computations necessary for the construction of forecast maps.

On the research side a profitable beginning has been made by T. Okada[8] and others in their investigations of weather correlations in the Pacific region. In closing, I wish to call attention to the desirability of applying to the Pacific certain correlations which have been worked out for the Atlantic Ocean. P. H. Gallé is now making winter temperature forecasts for central and western Europe on the basis of the strength of the trade winds during the preceding May to October.[9] February to March and March to April temperatures for the same region are indicated fairly well by the pressure gradient between Copenhagen and Stykkisholm during the preceding September to January, inclusive, or by the December water or air temperatures on the middle Norwegian coast.[10] The summer temperatures in all the Baltic region are indicated by the winter temperatures of the water about Iceland; and the general character of the April to September rainfall at Berlin, at least, is indicated by the Thorshavn rainfall of the preceding January to March.[11]

Expressed in terms of the Pacific region, these correlations would be as follows: The departures of the strength of the trade wind from the normal at Hawaii during the period May to October (perhaps earlier) may indicate a departure of the same sign in British Colombia during the months December to February following. The pressure gradient between Seattle and Dutch Harbor, September to January, inclusive, or the December air or water temperatures on the coast of southern Alaska when compared with the corresponding values of the year before may give a direct indication of the coming February to March and March to April temperatures relative to those of the same periods of the year before, which will probably have a chance of verification greater than 80 per cent in the region west of the continental divide and north of the forty-second parallel. Finally, the winter water temperatures at Dutch Harbor, and the January to March rainfall on the south Alaskan coast may give for the following summer a direct indication of the temperature and rainfall, respectively, for British Columbia and Washington.

These are, necessarily, rather generalized weather indications; and in themselves may not be of much use. They are, however, convenient as starting points for the many years of investigation which lie ahead of us to determine what the meteorological conditions of the North Pacific are, and how they may be used for making seasonal forecasts for the bordering lands, and with the help of Atlantic conditions, perhaps for the whole of North America.

[8] Journ. Meteorological Soc. of Japan, December, 1915, May and June, 1917; also, M. W. R., 1916, 44: 17–21, 238–240; 1917, 45: 299–300, 535–538.

[9] "On the relation between the summer changes of the North Atlantic trade winds and winter temperature in Europe." Proc. Amsterdam Roy. Acad. of Sci., vol. 18, 1916, pp. 1435–1448.

[10] W. Meinardus "Ueber einige meteorologische Beziehungen zwischen dem Nordatlantischen Ozean and Europe im Winterhalbjahr." Met. Zeits. 1898, 2 pl., pp. 85–104.

[11] H. H. Hildebrandsson "Quelques recherches sur les centres d'action de l'atmosphere." V. (last). Kungl. Svenska. Vetenskapsakad. Handl. Bd. 51, No. 8, 1914, 16 pp., 13 pl.

OCEAN TEMPERATURES AND SEASONAL WEATHER IN SOUTHERN CALIFORNIA.

By WM. E. RITTER and GEO. F. MCEWEN.

(Extracts from open letter, dated La Jolla, Cal., Nov. 9, 1918.)

So much does the well-being of the people of California and the whole western United States depend on the amount of precipitation and its time of occurrence each season, that even small, if trustworthy, [advance] indications would be valuable.

The researches on the ocean water off the coast of Southern California prosecuted by the Scripps Institution during the last 10 years, coupled with United States Weather Bureau records for the same time, bring to light somewhat suggestive facts.

Stated very briefly, they are these: During July, August, September, and October, 1917, the temperature of the sea at the institution averaged about 5° F. higher than for the same months of the preceding nine years, and the force of the northwest ocean wind for the same time was about 20 to 30 per cent below the average.

These exceptional conditions of water and wind were followed, as is well known, by exceptional weather conditions of the ensuing winter months. There was almost no rain until January, 1918, and the total precipitation was low for all California.

The conditions of sea and wind for summer and fall months of 1918 have repeated in essential features the conditions of those months for 1917.

As to the character of the data, there can be no question so far as concerns the sea temperatures at La Jolla for the period of February, 1916, to the present (November, 1918). Six temperatures a day, distributed evenly through the 24 hours, every day in the year except Sundays, are taken at the outer end of the institution pier; that is, where conditions are almost typically oceanic. In addition to this extensive and systematic series of temperatures many are taken at numerous stations near shore, and offshore to a distance of 75 to 100 miles from Point Conception to far south of the United States-Mexico boundary line. For the time previous to the completion and utilization of the pier, all temperature observations were of the distributed, intermittent kind, though in the aggregate large numbers were made.*

The defectiveness of the data in this case is the small number of years and the narrow area over which the observations extend. To give such data high predictive value, they would have to be extended over many years and over a far larger portion of the ocean.

As to the question of whether there are known cases elsewhere of connection between peculiar weather conditions on land and peculiar conditions of the ocean, it is to be said that while knowledge in this field is exceedingly meager, some of what we do possess indicates strongly the existence of such connections, and that investigations carried on long enough and widely enough will make possible seasonal and long range weather forecasting on the basis of a combination of atmospheric and oceanic observations much as daily forecasts are now made from observations on the atmosphere alone.[1]

* Cf. Summary and interpretation of hydrographic observations made by the Scripps Institution for Biological Research of the Univ. of California, 1908–1915. Univ. of Cal. Pubs. in Zool., Dec. 6, 1916, v. 15: 255–356, pls. 1–38.—Ed.

[1] Those who would like further information relative to oceanic conditions and their relation to the weather will find a popular treatment of these subjects in Bull. No. 7, of the Scripps Institution for Biological Research of the University of California, at La Jolla, Cal., by George F. McEwen, oceanographer, entitled: "Oceanic Circulation and Its Bearing Upon Attempts to Make Seasonal Weather Forecasts: a Sketch of Observational Methods and Explanations." The paper is now in the press and will soon be ready for distribution by the Scripps Institution.